SEASONALITY AND QUALITY OF EGGS PRODUCED BY FEMALE STRIPED BASS *(MORONE SAXATILIS)* IN THE SACRAMENTO AND SAN JOAQUIN RIVERS

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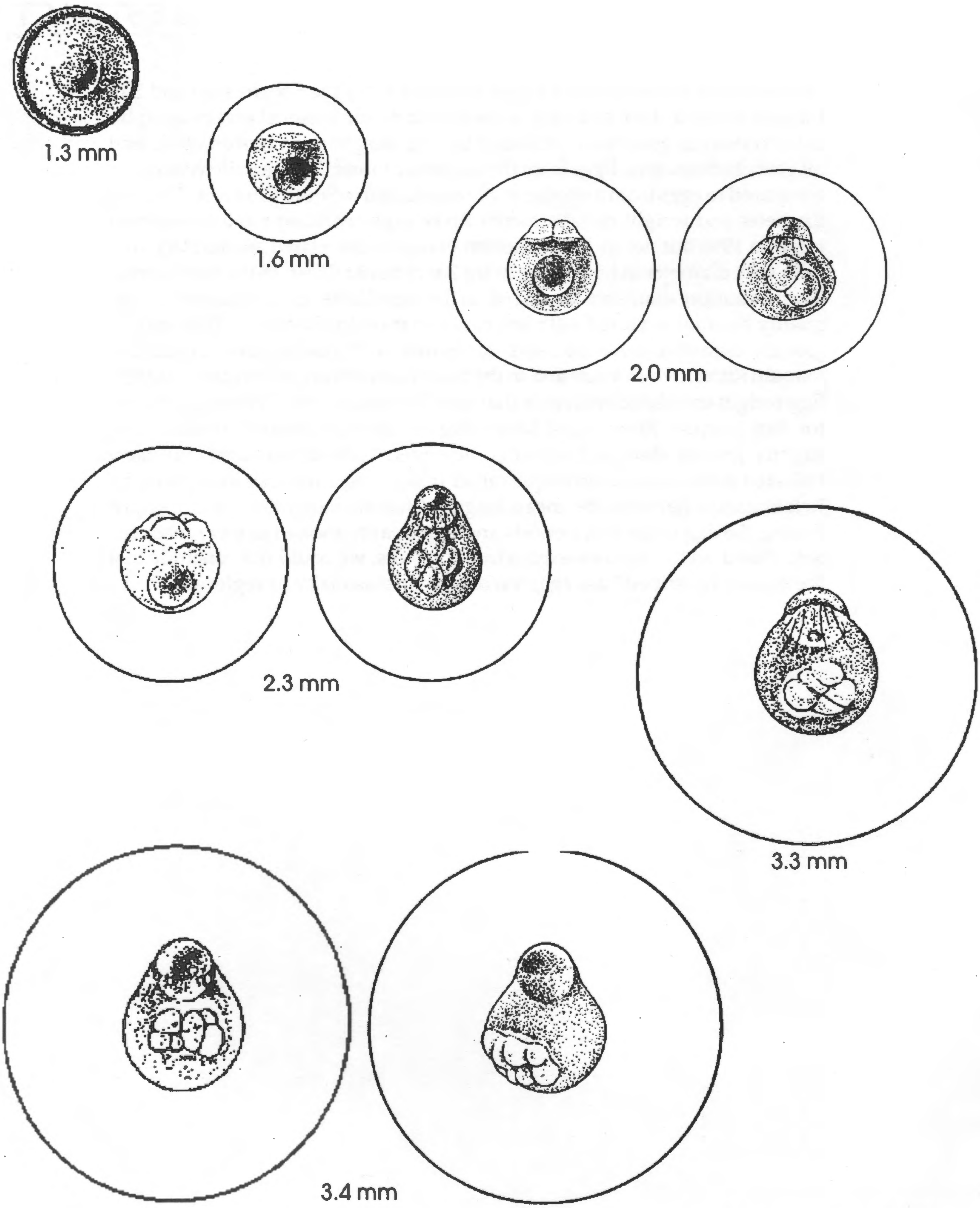
Striped bass (*Morone saxatilis*) eggs collected from the Sacramento and San Joaquin rivers in 1990 and 1991 were examined for seasonal and geographical variation in quality as measured by egg weight and chorion, yolk, and oil globule diameters. Eggs from the Sacramento and San Joaquin rivers were compared to eggs from a similar study conducted in South Carolina. Chorion diameter and weight of Sacramento River eggs exhibited a minor seasonal trend in 1990 but not in 1991. Chorion diameter correlated moderately well with yolk diameter in both years in the Sacramento River. In the San Joaquin River, chorion diameter appeared to be unreliable as a measure of egg quality because it varied with ion concentration in the water. Yolk and oil globule diameter measurements correlated with one another in the San Joaquin River in both years and in the Sacramento River in 1991 but not 1990. Egg weight correlated with yolk diameter for Sacramento River eggs but not for San Joaquin River eggs. Mean egg weights in South Carolina were slightly greater than in California; however, these differences may have reflected differences in technique rather than a true difference in egg weight. Relationships between the mean length of female bass netted and trapped during the egg collection periods and egg quality measures were inconsistent. Based on the inconsistencies in our results, we could not conclude that the quality of striped bass eggs varied either seasonally or regionally.



Figures from Mansueti, 1958.

INTRODUCTION

Striped bass support one of California's most important sport fisheries.[1] Sport fishing for striped bass in the Sacramento-San Joaquin estuary has declined commensurately with declining striped bass abundance, which is now less than one-third of that in the 1960s.[2]

Female age and condition determine nutritional content and viability of striped bass eggs.[3] Fat content of female muscle in some fish species linearly correlates with protein content of eggs and survival of embryos, and lipid content of eggs increases with female age.[4] Some research on pelagic spawning fish suggests larger females produce larger eggs.[5] Notably, in the Chesapeake estuary, female striped bass weighing more than 4.5 kg produced eggs that were 1.5 times heavier than eggs produced by females weighing 4.5 kg or less.[6]

Our study evaluated trends in potential egg quality measures that may influence striped bass egg viability within the Sacramento-San Joaquin river system. We measured egg weight, chorion, yolk, and oil globule diameters and compared them to mean female length. These variables were compared with each other and with similar measurements of eggs from the Santee-Cooper river system in South Carolina.

1 Meyer Resources, Inc. 1985.
2 Stevens 1980; Stevens *et al* 1985.
3 Eldridge *et al* 1982; Zastrow *et al* 1989.
4 Kjørsvik *et al* 1990.
5 Bagenal 1971.
6 Zastrow *et al* 1989.

MATERIALS AND METHODS

In 1990 and 1991, striped bass eggs were subsampled from collections of the annual egg and larval survey conducted each year by the Interagency Ecological Studies Program.[7] Collections covered the major portion of the spawning period in the two major spawning areas of the Sacramento and San Joaquin rivers (Figure 1). In 1990, sampling lasted 63 days on the Sacramento River and 32 days on the San Joaquin River. In 1991, sampling spanned 34 days on the Sacramento River and 26 days on the San Joaquin River.

Samples were preserved in unbuffered 5% formalin. Only eggs with intact chorions and yolks were evaluated. Samples included both early- and late-stage eggs. Each week from each spawning area, 50 eggs were subsampled from the sample containing the greatest number of eggs. If less than 50 eggs were available from that sample, additional eggs were obtained from adjacent stations sampled on the same day or from the same or adjacent stations sampled on another day during the same week. If there were still less than 50 eggs, all eggs collected at all stations that week were used. The smallest group examined contained 20 eggs.

Chorion, yolk, and oil globule diameters were measured to the nearest 0.1 mm using an ocular micrometer. Before weighing, eggs were rinsed twice in distilled water. Each rinse lasted 1 minute. Then each sample's eggs were divided evenly, according to size, into 60 groups in 1990 and 80 groups in 1991. Groups range from four to ten eggs, depending on the total number in the sample.

Eggs were weighed on boats that were coded and weighed to the nearest 10 µg before a group of eggs was added. Plastic weigh boats were used in 1990 and aluminum weigh boats in 1991. Aluminum weigh boats were dried before eggs were added; plastic weigh boats were not. To determine dry weight in both years, eggs were dried for 24 hours at 60°C before weighing. In 1991, a 48-hour dry weight also was measured after eggs were dried for an additional 24 hours. Weigh boats were cooled in a dehydrator before weighing.

In both years, weight gained or lost by the weigh boats was determined by weighing empty "control" boats. The control boats were coded, dried, and weighed simultaneously with weigh boats containing eggs. The percentage of weight change for each control boat was calculated and averaged by group to calculate a correction factor. The correction factor was used to adjust for changes of the weigh boat.

Total egg weight was determined by adjusting the boat weight according to the percentage of change in the control boats and then subtracting corrected boat weight from total boat plus egg weight. Because of error induced by not drying before weighing, egg weight measurements were more variable in 1990 than in 1991. To reduce this variability, egg weights less than 160 µg and greater than 340 µg were eliminated from the 1990 analysis. These weights were outside the range of weights measured in 1991. The 1991 weights were based on averages of the 24- and 48-hour egg weights. To determine mean individual egg weights, each weigh boat group's total egg weight was divided by the number of eggs in the group.

Seasonal and geographic variability in the egg quality measures and relationships between these measures were examined graphically and/or by correlation or regression analysis. Chorion diameters also were correlated against specific conductance of the water from which the eggs were collected. The relationship between egg quality and female size was evaluated by comparing egg quality variables with mean length of female striped bass measured during adult striped bass tagging.[8]

7 Low and Miller 1986.
8 Stevens 1977.

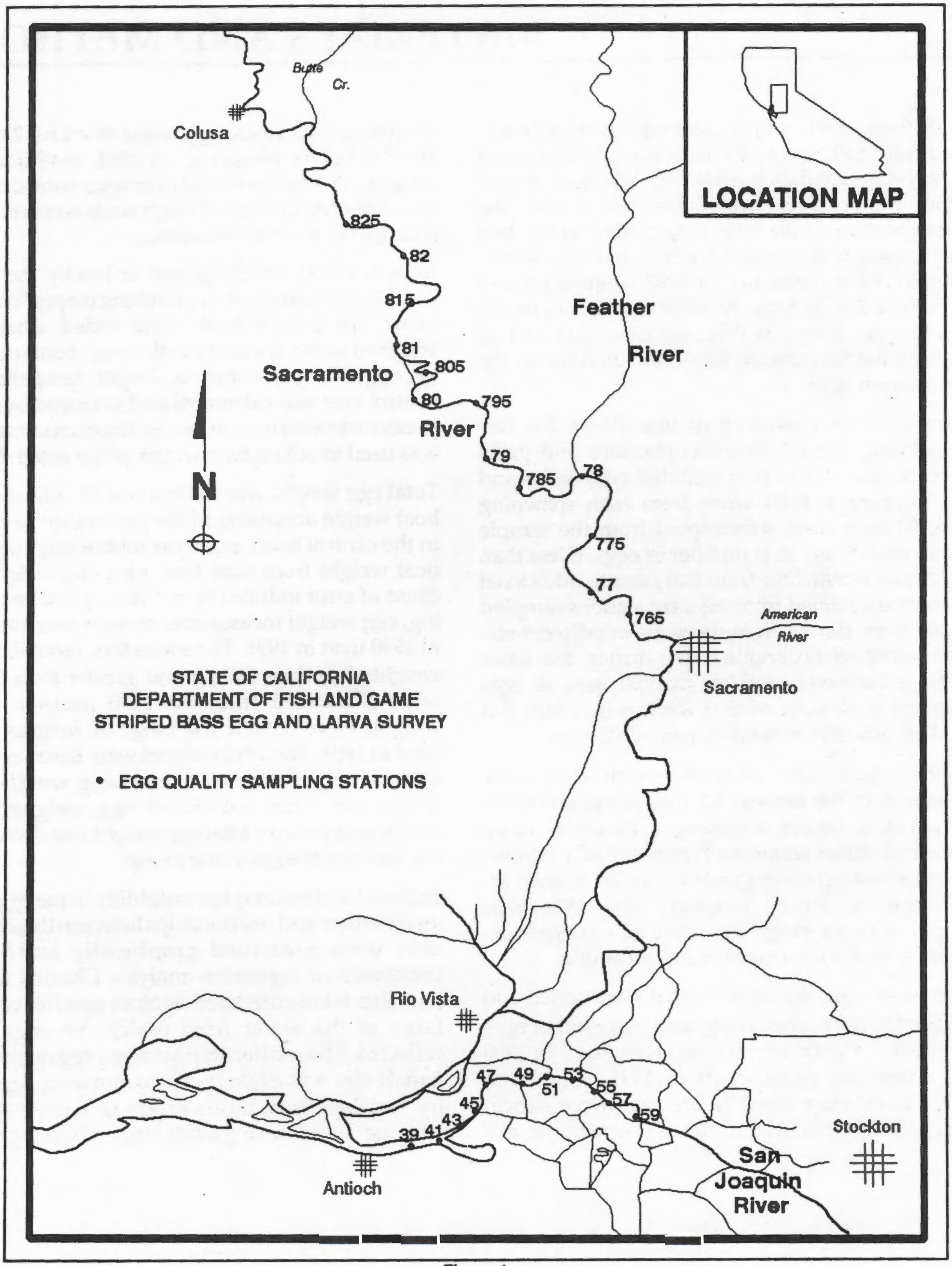


Figure 1
EGG AND LARVAL STATIONS USED FOR THE EGG QUALITY STUDY

Weight

Mean weight of striped bass eggs from the Sacramento River was 240 µg (range 160-300 µg) in 1990 and 260 µg (range 170-330 µg) in 1991 (Table 1). In the San Joaquin River, mean egg weight was 280 µg (range 160-340 µg) in 1990 and 240 µg (range 200-300 µg) in 1991 (Table 1). In both years, mean egg weight was variable and did not exhibit a striking seasonal trend (Figures 2 and 3).

Chorion, Yolk, and Oil Globule Diameter

In the Sacramento River, a decreasing trend was evident in chorion diameter from about 3.6 mm on day 112 to 2.8 mm on day 167 in 1990 (Figure 2). No persistent seasonal trend was apparent in 1991, although the smallest average diameter was 2.9 mm on day 148, the last sampling day. Yolk and oil globule diameter varied little over the season in the Sacramento River and exhibited no seasonal trend.

Chorion diameter of San Joaquin River eggs varied more dramatically than that of Sacramento River (Figure 3). Whether this greater variation was due to variation in ion content of the San Joaquin River water is not evident from correlations between chorion diameter and specific conductance. Chorion diameter for the San Joaquin River did not correlate significantly with specific conductance in either 1990 ($r = 0.18$, $P<0.05$) or in 1991 ($r = -0.64$, $P<0.05$) (Table 2).

Yolk and oil globule diameters of eggs from the San Joaquin River exhibited no seasonal trend in 1990. An increasing trend in yolk and oil globule diameter over time after day 120 is evident in 1991 (Figure 3). Yolk diameter increased from about 0.7 mm on day 120 to about 1.1 mm on day 144; oil globule diameter increased from about 0.5 mm to about 0.8 mm during the same period.

Mean length of female striped bass trapped in fyke nets in the Sacramento River decreased over time during both 1990 and 1991 (Figure 4). In contrast, length of female striped bass captured in gill nets in the San Joaquin River exhibited an increasing trend until the middle of the season in both years, after which mean length began decreasing (Figure 5).

Table 1
Striped Bass Egg Quality Measurements in California and South Carolina

N represents the number of groups from which average diameters and weights were derived.
N^A represents the number of groups used to determine egg weight after eliminating out-of-range egg weights.
Standard error for each measurement is in parentheses.

Year	River	Yolk Diameter (mm)	Oil Globule Diameter (mm)	Egg Weight (µg)	N	N^A
California						
1990	Sacramento	1.2 (0.01)	0.9 (0.03)	240 (5.8)	35	28
	San Joaquin	1.2 (0.02)	0.7 (0.01)	280 (22.5)	25	12
1991	Sacramento	1.1 (0.01)	0.8 (0.01)	260 (3.6)	50	
	San Joaquin	1.0 (0.02)	0.7 (0.01)	240 (2.9)	30	
South Carolina*						
1990	Congaree	1.1 (0.06)	0.7 (0.04)	**	30	
	Wateree	1.1 (0.04)	0.7 (0.04)	**	16	
1991	Congaree	NR	NR	279 (5.0)	7	
	Wateree	NR	NR	315 (5.9)	7	

* South Carolina data were provided by James Bulak, South Carolina Wildlife and Marine Resources Department.
** Data were not used because techniques changed.
NR Data were not reported.

Table 2
Mean Chorion Diameter of Eggs and Mean Specific Conductance of the Water at Egg Collection Stations, San Joaquin River, 1990 and 1991

Year	Date	Chorion Diameter (mm)	Specific Conductance (µS/cm)
1990	Apr 14	2.0	3024
	Apr 22	1.9	1528
	May 4	2.1	1517
	May 8	3.0	2088
	May 16	2.7	2478
1991	Apr 28	3.4	959
	Apr 30	2.6	217
	May 12	2.2	1867
	May 14	2.4	1374
	May 16	3.3	339
	May 24	3.2	324

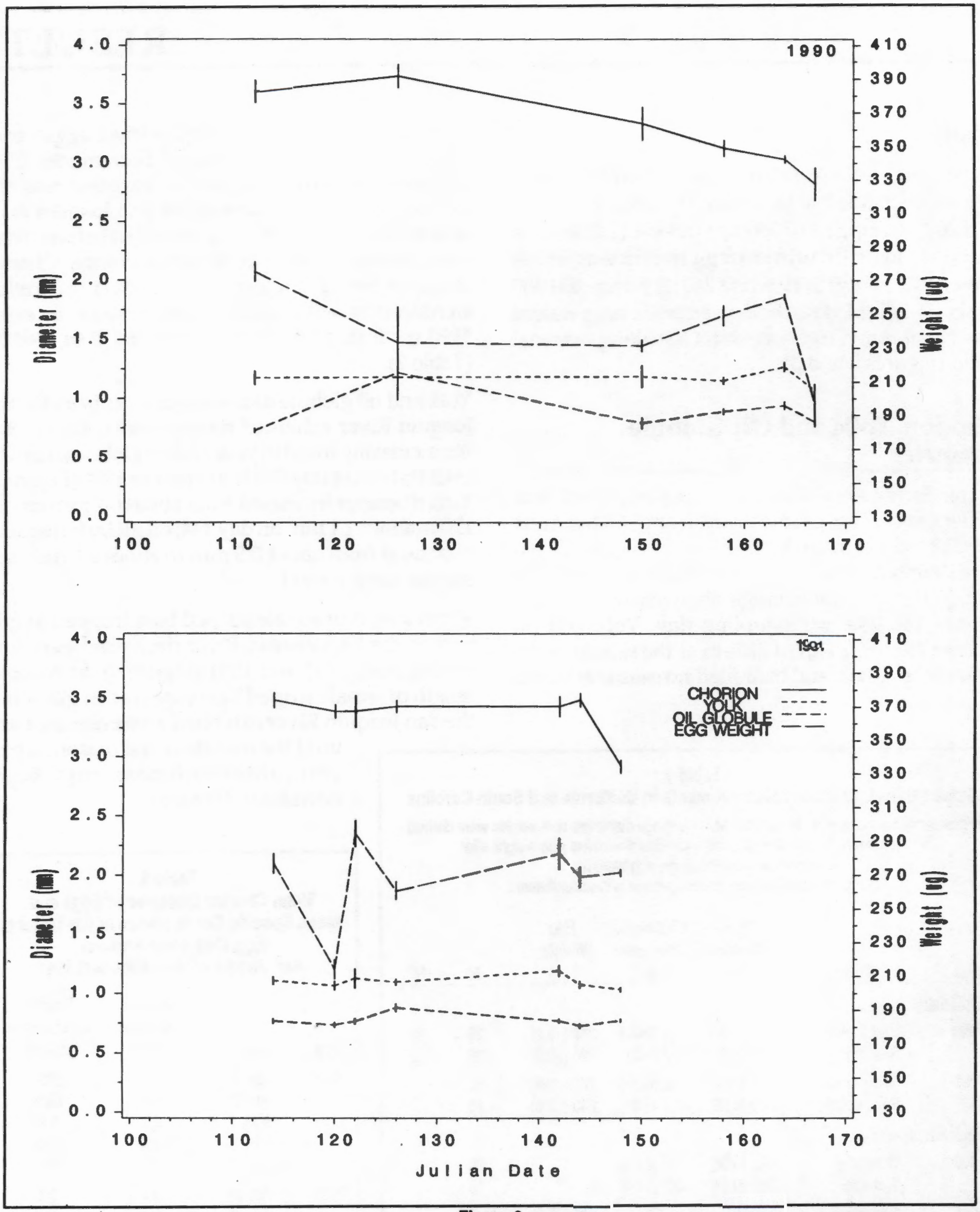


Figure 2

CHORION, YOLK, AND OIL GLOBULE DIAMETER AND EGG WEIGHT, SACRAMENTO RIVER, 1990 AND 1991

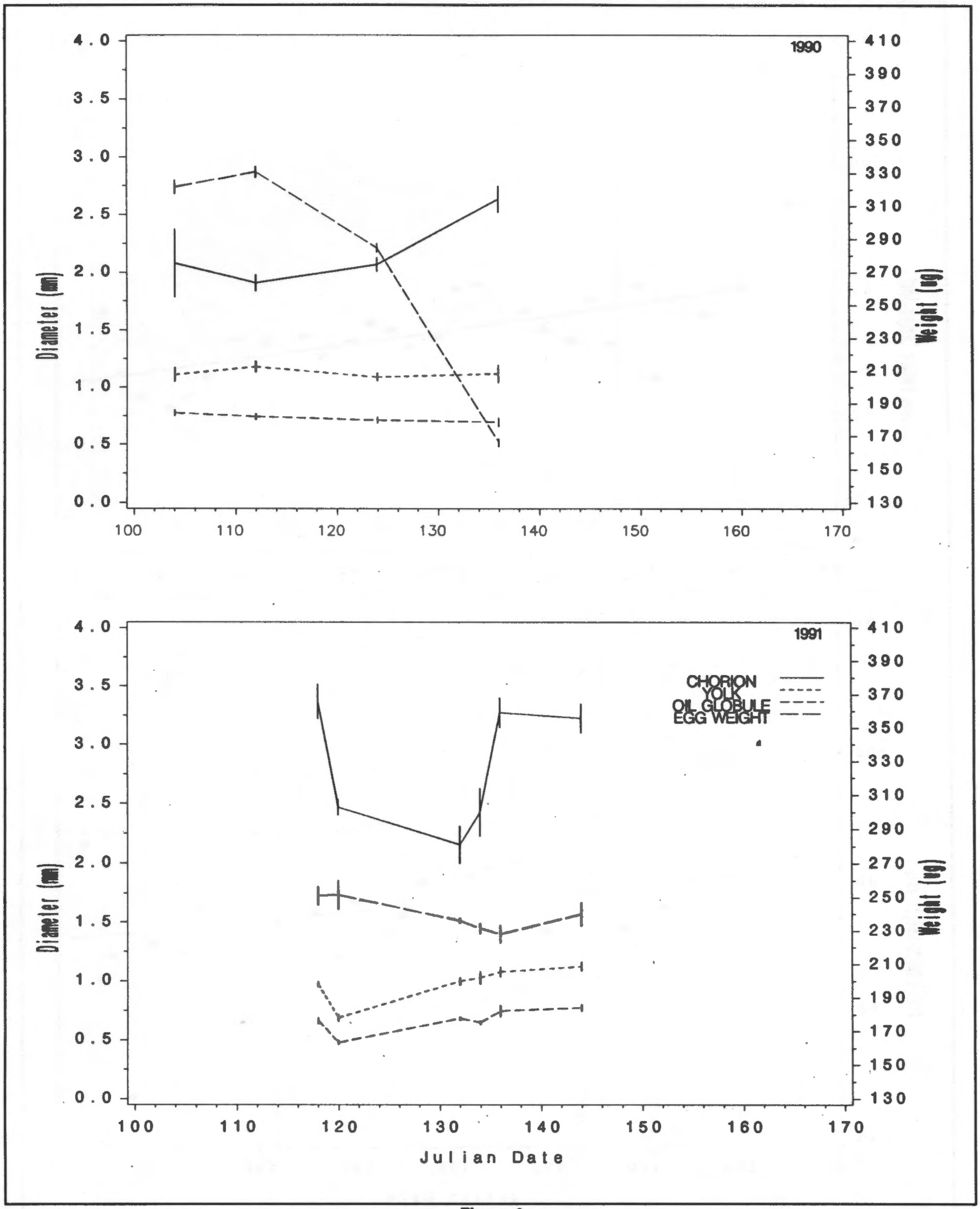


Figure 3
CHORION, YOLK, AND OIL GLOBULE DIAMETER AND EGG WEIGHT, SAN JOAQUIN RIVER, 1990 AND 1991

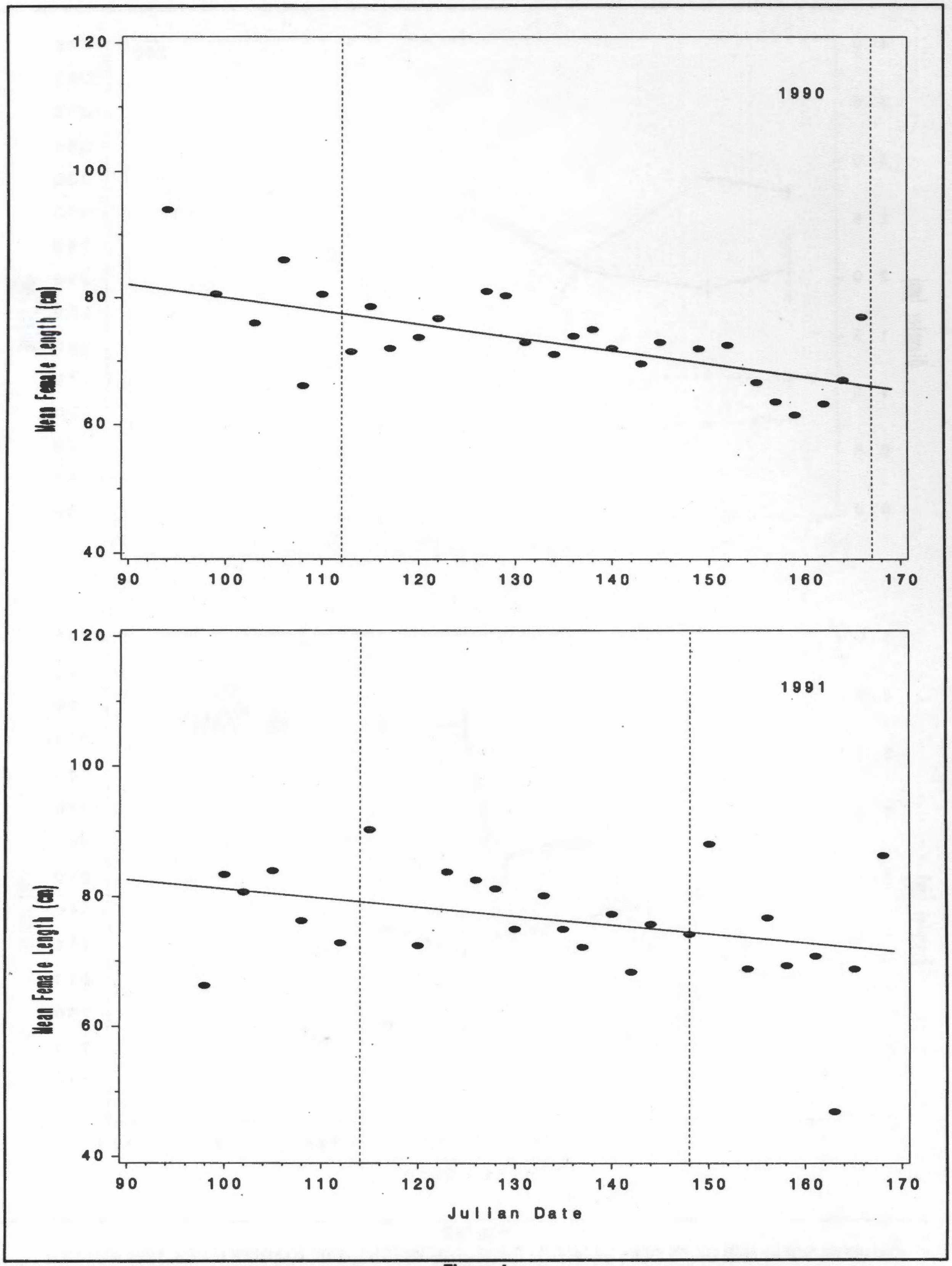


Figure 4

TRENDS IN DAILY MEAN LENGTH OF STRIPED BASS TRAPPED IN THE SACRAMENTO RIVER, 1990 AND 1991

Vertical lines represent the beginning and ending dates of the egg quality study.

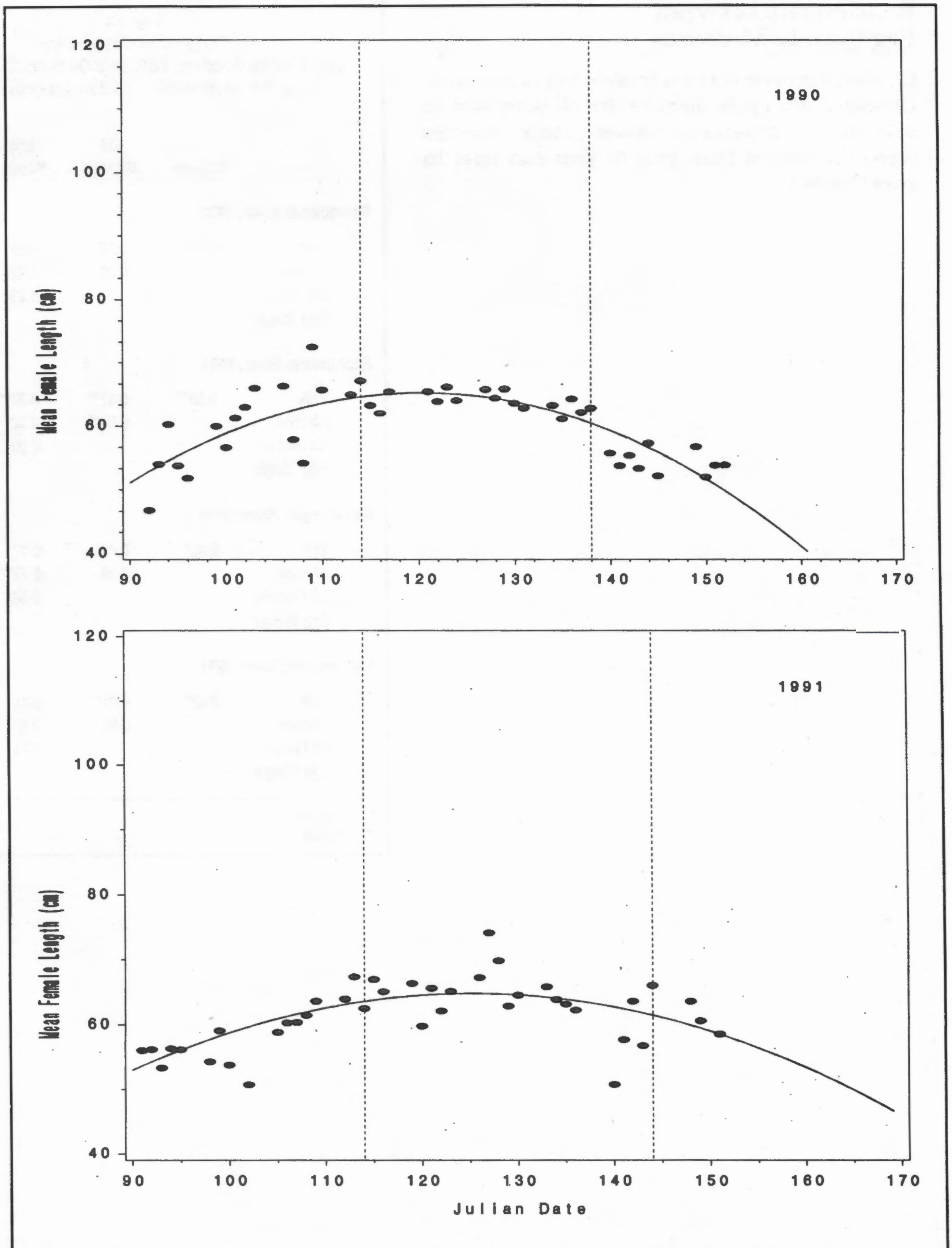


Figure 5

TRENDS IN DAILY MEAN LENGTH OF STRIPED BASS NETTED IN THE SAN JOAQUIN RIVER, 1990 AND 1991

Vertical lines represent the beginning and ending dates of the egg quality study.

Relationship between Egg Quality Measures

Chorion diameter was moderately but consistently correlated with yolk diameter for all years and in both rivers. Correlations between other variables were inconsistent from year to year and river to river (Table 3).

Table 3
Correlation Matrices for Egg Weight, Chorion, Yolk, and Oil Globule Diameter from the Sacramento and San Joaquin Rivers

	Chorion	Oil Globule	Egg Weight	Female Length
Sacramento River, 1990				
Yolk	0.55**	0.17	0.61**	-0.19
Chorion		0.28	0.42*	0.95**
Oil Globule			0.05	0.19
Egg Weight				-0.16
Sacramento River, 1991				
Yolk	0.58**	0.47**	0.37**	0.28
Chorion		0.36**	0.32*	0.04
Oil Globule			0.22	0.20
Egg Weight				0.02
San Joaquin River, 1990				
Yolk	0.48*	0.43*	-0.17	0.05
Chorion		0.38	-0.73**	0.21
Oil Globule			0.53	-0.22
Egg Weight				-0.11
San Joaquin River, 1991				
Yolk	0.42*	0.91**	-0.11	0.80*
Chorion		0.53**	0.12	0.36
Oil Globule			-0.04	0.73*
Egg Weight				-0.16

* $P \leq 0.05$
** $P \leq 0.01$

DISCUSSION

This study did not clearly define variation in the quality of eggs produced by striped bass. A general relationship between egg diameter and egg weight was evident only in modest correlations between mean egg weight and chorion and yolk diameters for Sacramento River eggs. Correlations of egg weight with these measures in the San Joaquin River and with oil globule in both rivers were either weak or inconsistent. The only consistent correlations among "quality measures" were moderate correlations between chorion and yolk diameters.

This study did not provide convincing evidence that egg quality exhibited seasonal trends in the Sacramento and San Joaquin river systems.

Some seasonal variation in chorion diameter may have been in response to variations in ion concentration in the river water. Chorion diameter tends to decrease when salinity increases.[9] The negative, albeit nonsignificant, correlation between chorion diameter and specific conductance in 1991 in the tidal San Joaquin River is consistent with this tendency. The Sacramento River spawning area is not influenced by salinity; therefore, salinity would not influence chorion diameter.

In Chesapeake Bay, larger female striped bass produce larger eggs.[10] Correlations between female length and yolk and oil globule diameters in the San Joaquin River in 1991 and with chorion diameter in the Sacramento River in 1990 are consistent with Chesapeake Bay results. However, egg weight and the other diameter measurements were not highly correlated with female length. Our results may be confounded by sampling eggs and females separately rather than comparing egg diameter with the length of the female from which they were actually taken.

No geographical variation was found in the quality of striped bass eggs produced by striped bass females in Chesapeake Bay tributaries.[11] Similarly, there were no consistent differences in the various egg quality measures between the Sacramento and San Joaquin rivers.

Except for the San Joaquin River mean egg weight of 280 µg in 1990, South Carolina mean egg weights were significantly greater than the other means of 240-260 µg in California ($Z=3.76$; $P<0.05$; nonparametric Wilcoxon test[12]). In 1991, mean weight of striped bass eggs from the Congaree River was 279 µg and from the Wateree River was 315 µg[13] (Table 1). The weight differences may reflect variation in techniques between locations rather than a true geographic difference. For example, only early-stage eggs were used in South Carolina, but both early- and late-stage eggs were used in our study. In contrast to the weight differences, yolk and oil globule diameter measurements of eggs from the Sacramento and San Joaquin rivers were similar to eggs from the South Carolina rivers (Table 1). Chorion diameter was not reported for South Carolina.

Several improvements in techniques could be implemented if this study were to be repeated.

- Lighter weigh boats should be used to reduce apparent egg weight variability induced by weigh boats.
- Eggs should be collected over more of the spawning season to enhance the possibility of detecting relationships between egg and female size.
- Eggs from artificially spawned females could be measured and weighed for direct comparison of eggs and female size.
- To determine energy available to offspring, caloric content of eggs could be measured using a bomb calorimeter.[14]
- Chorion diameter need not be recorded, because it is affected by ions in the water and is probably not a good quality indicator.

9 Southward and Demir 1974.
10 Zastrow *et al* 1989.
11 Zastrow *et al* 1989.
12 SAS 1988.
13 Jean B. Kinard, South Carolina Wildlife and Marine Resources Department, unpublished report.
14 Eldridge *et al* 1982.

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SCIENTIFIC NAMES OF FISH

American eel	*Anguilla rostrata*
American shad	*Alosa sapidissima*
bay goby	*Lepidogobius lepidus*
bigscale logperch	*Percina macrolepida*
black bullhead	*Ameiurus melas*
black crappie	*Pomoxis nigromaculatus*
blue catfish	*Ictalurus furcatus*
bluegill	*Lepomis macrochirus*
brown bullhead	*Ameiurus nebulosus*
brown trout	*Salmo trutta*
California halibut	*Paralichthys californicus*
California roach	*Hesperoleucus symmertricus*
chameleon goby	*Tridentiger trigonocephalus*
channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
common carp	*Cyprinus carpio*
delta smelt	*Hypomesus transpacificus*
English sole	*Pleuronectes vetulus*
fathead minnow	*Pimephales promelas*
golden shiner	*Notemigonus crysoleucas*
goldfish	*Carassius auratus*
green sturgeon	*Acipenser medirostris*
green sunfish	*Lepomis cyanellus*
hardhead	*Mylopharodon conocephalus*
hitch	*Lavinia exilicauda*
inland silverside	*Menidia beryllina*
jacksmelt	*Atherinopsis californiensis*
largemouth bass	*Micropterus salmoides*
longfin smelt	*Spirinchus thaleichthys*
mosquitofish	*Gambusia affinis*
northern anchovy	*Engraulis mordax*
Pacific herring	*Clupea pallasii*
Pacific lamprey	*Lampetra tridentata*
pink salmon	*Oncorhynchus gorbuscha*
plainfin midshipman	*Porichthys notatus*
prickly sculpin	*Cottus asper*
pumpkin seed	*Lepomis gibbosus*
rainwater killifish	*Lucania parva*
redear sunfish	*Lepomis microlophus*
red shiner	*Cyprinella lutrensis*
riffle sculpin	*Cottus gulosus*
river lamprey	*Lampetra ayresii*
Sacramento blackfish	*Orthodon microlepidotus*
Sacramento perch	*Archoplites interruptus*
Sacramento splittail	*Pogonichthys macrolepidotus*
Sacramento squawfish	*Ptychocheilus grandis*
Sacramento sucker	*Catostomus occidentalis*
shiner surfperch	*Cymatogaster aggregata*
silver salmon	*Oncorhynchus kisutch*
smallmouth bass	*Micropterus dolomieu*
speckled dace	*Rhinichthys osculus*
speckled sanddab	*Citharichthys stigmaeus*
splittail	*Pogonichthys macrolepidotus*
staghorn sculpin	*Leptocottus armatus*
starry flounder	*Platichthys stellatus*
steelhead trout	*Oncorhynchus mykiss*
striped bass	*Morone saxatilis*
striped mullet	*Mugil cephalus*
surf smelt	*Hypomesus pretiosus*
threadfin shad	*Dorosoma petenense*
threespine stickleback	*Gasterosteus aculaetus*
tui chub	*Gila bicolor*
tule perch	*Hysterocarpus traski*
wakasagi	*Hypomesus nipponensis*
warmouth	*Lepomis gulosus*
white catfish	*Ameiurus catus*
white crappie	*Pomoxis annularis*
white croaker	*Genyonemus lineatus*
white sturgeon	*Acipenser transmontanus*
yellow bullhead	*Ameiurus natalis*
yellow perch	*Perca flavescens*
yellowfin goby	*Acanthogobius flavimanus*

COMMON ABBREVIATIONS AND METRIC CONVERSIONS

Area

km^2	square kilometers; to convert to square miles, multiply by 0.3861
m^2	square meters; to convert to square feet, multiply by 10.764

Length

cm	centimeters; to convert to inches, multiply by 0.3937
FL	fork length; length from the most anterior part of a fish to the median caudal fin rays (fork in the tail)
km	kilometers; to convert to miles, multiply by 0.62139
m	meters; to convert to feet, multiply by 3.2808
mm	millimeters; to convert to inches, multiply by 0.03937
SL	standard length; tip of upper jaw of a fish to crease formed when tail is bent sharply upward
TL	total length; length from the most anterior part of a fish to the end of the tail

Volume

AF	acre-foot; equal to 43,560 cubic feet
L	liters; to convert to quarts, multiply by 1.05668; to convert to gallons, multiply by 0.26417
mL	milliliters

Flow

cfs	cubic feet per second; to convert to acre-feet per day, multiply by 1.98
gpm	gallons per minute
mgd	million gallons per day

Velocity

fps	feet per second
m/s	meters per second; to convert to feet per second, multiply by 3.2808

Mass

kg	kilograms; to convert to pounds, multiply by 2.2046

Concentration

mg/L	milligrams per liter; equals parts per million (ppm)
µg/L	micrograms per liter; equals parts per billion (ppb)

Specific Conductance

µS	microsiemens; equivalent to micromhos
µS/cm	microsiemens per centimeter

Temperature

°C	degrees Celsius; to convert to °F, multiply by 1.8 then add 32 degrees
°F	degrees Fahrenheit; to convert to °C, subtract 32 degrees then divide by 1.8

Mathematics and Statistics

df	degrees of freedom
e	base of natural logarithm
E	expected value
log	logarithm
N	sample size
NS	not significant
%	percent
‰	per thousand
P	probability
r	correlation or regression coefficient (simple)
R	correlation or regression coefficient (multiple)
SD	standard deviation
SE	standard error
V	variance

Interagency Program Members

COE	U.S. Army Corps of Engineers
DFG	California Department of Fish and Game
DWR	California Department of Water Resources
EPA	U.S. Environmental Protection Agency
FWS	U.S. Fish and Wildlife Service
SWRCB	California State Water Resources Control Board
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey

General

CPUE	catch per unit effort
YOY	young of the year